Cost Analyses of Fuel Cell Stack/Systems

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Objectives

To develop an independent cost model for proton exchange membrane (PEM) fuel cell systems for transportation applications and to assess cost reduction strategies for year 2000 to 2004 development projects

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- N. Cost (Fuel-Flexible Fuel Processor)
- O. Stack Material and Manufacturing Cost

Technical Targets

System	Efficiency	Cost	
		2010	2015
Direct Hydrogen Fuel Cell Power System (including hydrogen storage)	60%	$45/kWe	$30/kWe
Reformer-based Fuel Cell Power System - clean hydrocarbon or alcohol based fuel - 30 second start-up - satisfies emissions standards	45%		

Approach

- In the first two years, develop a baseline system configuration and cost estimate based on best available and projected technology and manufacturing practices, and assess the impact of potential technology developments on system cost reduction
- In the subsequent four years, annually update the baseline cost model and system scenarios based on assessments of developments in PEM fuel cell system technologies and manufacturing processes.

Accomplishments

- Evaluated status of bipolar plate technology for PEM fuel cells (Table 1)
- Compared cost and performance of graphite and metallic bipolar plates
- Examined performance impact of using graphite bipolar plates instead of metallic bipolar plates

Table 1. Overview of Bipolar Plate Technologies Considered in this Analysis

Substrate Material	Coating Material	
	Non-Metal	**Metal-Based**
Aluminum	Graphite	Noble Metals (gold, silver)
Stainless Steel	Conductive Polymer	Metal Carbides
Ni-Cr alloys		Metal Nitrides
Metal/polymer composite		Cladding

Future Directions

Develop projections of future system performance and cost based on continued industry feedback, alternative system scenarios, and projected technology developments

Introduction

In 1999, a baseline cost estimate for a 50-kW PEM fuel cell system for passenger vehicles was developed based on technology available in the year 2000, but using a high production volume scenario (i.e., 500,000 units per year). In 2000, we solicited feedback from system and component developers on the system configuration, design and performance parameters, and manufacturing process and costing assumptions. The impacts of alternative system design approaches were also assessed: specifically, what would be the impact of sizing the stack at the high power point rather than 0.8 volts, and what would be the impact of hybridization, i.e., reducing or increasing rated power, on the fuel cell system power cost ($/kW). In 2001, we focused on the development of future costs based on projected technology. In 2002, an electrochemical model for the relationship between catalyst loading, temperature, pressure, and power density was combined with the cost model to understand the tradeoffs between catalyst loading and cost of the stack. The cost model was used to develop projections for direct hydrogen fueled systems. In 2003, we evaluated the impact of replacing graphite bipolar plates with metallic bipolar plates.

The potential benefits of metallic bipolar plates that we analyzed were reduced plate thickness and weight and improved thermal and electrical conductivity. Higher electrical conductivity increases the efficiency of the system by decreasing parasitic loss, which enables the formation of smaller stacks. Similarly, lighter weight increases power density [kW/kg]. Thinner plates decrease the thermal management and the packaging requirements, which increases the applicability of PEM fuel cells in the automotive industry. All of these benefits may lead to lower cost (Figure 1). Finally, recyclability and consistency of metal forming technologies were considered as additional benefits of metallic bipolar plates.

Approach

The assessment of bipolar plate technology for PEM fuel cells was started with the initial hypothesis

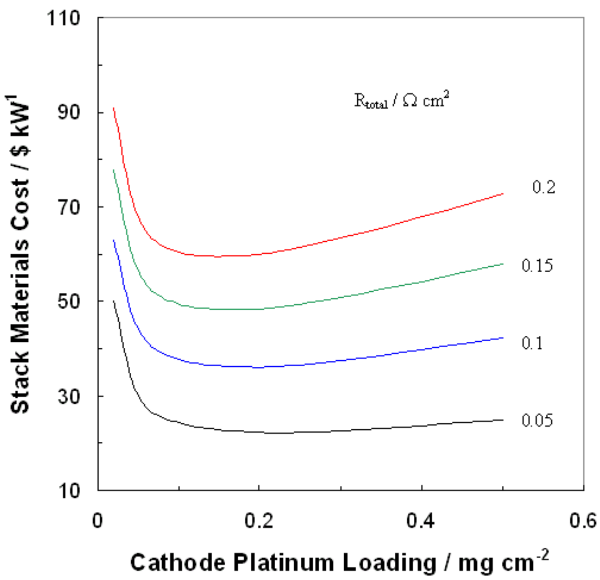


Figure 1. QUANTUM Compressed Hydrogen Storage

that metallic bipolar plates may lower stack cost by reduction of ohmic losses, and that increased volumetric power density would enhance integration into vehicles. The following comparative parameters were considered:

- thickness (and its impact on volumetric density)
- weight
- thermal conductivity
- electrical conductivity (bulk and interfacial resistance)
- material and processing cost

Metallic bipolar plates were analyzed by evaluating the alternatives for substrate material and coating technology. Thermal and electrical properties and feasible dimensions were studied.

Industry representatives from the bipolar plate and coating industries and material suppliers were contacted to identify benefits and drawbacks of metallic and graphite bipolar plates (Table 2).

Results

Interfacial resistance between the bipolar plate and the electrode dominates bulk resistance for both graphite and metal bipolar plates. There was no

Table 2. Benefits and Drawbacks of Graphite, Composite and Metallic Bipolar Plates

	Graphite (machined)	Metal (SS, Al, Ti)	Graphite Composite
Benefits	• Stability • Low specific density • Low contact resistance with electrodes • Corrosion resistance	• High Thermal conductivity • Recyclable • Consistent product	• Lower contact resistance • Corrosion resistance
Drawbacks	• Expensive to machine • Brittle • Thick	• Needs coating • Membrane poisoning • Formation of insulating surface oxides	• Low bulk conductivity

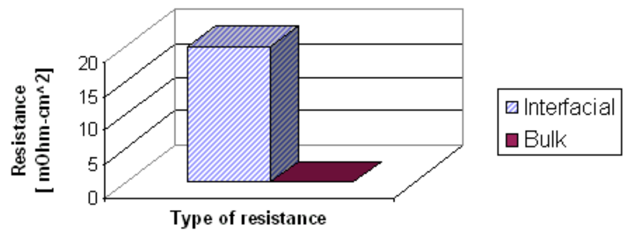


Figure 2. Bulk and Interfacial Contact Resistance for Stainless Steel Alloy SS 904 L Bipolar Plates

evidence indicating that the interfacial resistance for metallic plates was lower than graphite's. Therefore, metal's smaller bulk resistance (9.5 x10^{-3} mΩ-cm^2 vs. 9 mΩ-cm^2) is not a clear advantage (Figure 2).

The cost of thinner and highly corrosion resistant metallic plates (i.e. SS 904 L) is not lower than thicker graphite-based plates. As an example, the cost per plate (1 mm thick, 603 cm^2) made of 904L was calculated to be $10.31, compared to $2.75 per graphite-based plate (3.75 mm thick, 603 cm^2), as shown in Table 3. Application of the conductive coating further increases the cost of the substrate.

A three-fold decrease in the thickness of the bipolar plate (e.g. 3.75 to 1 mm) decreases the stack volume by at least 50% and the overall system volume by at least 10%. However, graphite plate thickness is approaching values of 1 mm, similar to metallic bipolar plates. Flow field requirements and mechanical robustness set minimum dimensions, regardless of manufacturing feasibility. Therefore, although thinner plates have a significant effect on

Table 3. Metallic and Graphite Plate Costs (all costs are in U.S. dollars)

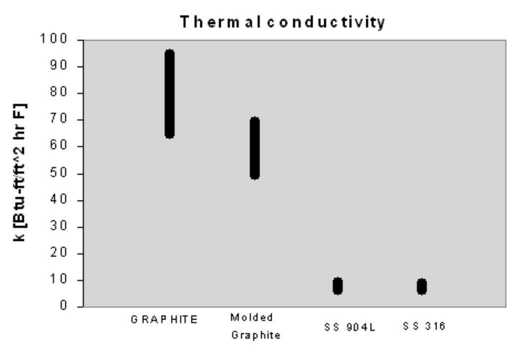
Plate Type	Graphite Baseline	Metallic – SS 316	Metallic - SS 904
Substrate Material Cost [$/plate]	2.24	2.22	5.42
Substrate Material Cost [$/m^2]	37	37	90
Processing Cost [$/plate]	0.51	1.07	1.07
Processing Cost [$/m^2]	8	18	18
Coating Cost [$/plate]	No	3.79	3.79
Coating Cost [$/m^2]	No	63	63
TOTAL [$/plate]	2.75	7.08	10.31
TOTAL [$/m^2]	46	117	171
TOTAL STACK COST for BIPOLAR PLATES [$/kW]	21	53	78
Weight [kg]	179	228	225

volumetric density, they can be achieved by using both graphite and metal.

Thermal conductivity of metallic bipolar plates based on stainless steel is not superior to molded graphite (Figure 3).

Conclusions

- Metallic bipolar plates do not offer a clear performance or cost advantage over graphite-based bipolar plates.
- Cost of bipolar plates could increase 23-40% relative to graphite plates depending on the stainless steel alloy used.
- Metallic bipolar plates do not result in significantly higher volumetric density.
- Thermal management requirements for metallic bipolar plates are not more favorable than requirements for graphite plates.
- Development of effective coatings are critical to the viability of metallic bipolar technology.



Note: The thermal conductivity for molded graphite was assumed to be the weighted average of the properties of vinyl ester polymer (31.2%) and pure graphite (65%).

Figure 3. Thermal Conductivity of Different Materials

FY 2003 Publications/Presentations

1. *Fuel Cell Cost Issues.* SAE TOPical TEChnical Symposium. April 8-9, 2003. Dearborn, Michigan.
2. 2003 Annual Hydrogen, Fuel Cells & Infrastructure Technologies Program Merit Review and Peer Evaluation in Berkeley, California.